# AN EVALUATION OF PRODUCTS FOR WASHING AIRPLANES AND THEIR EFFECTS ON CORROSION

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## ABSTRACT

This paper presents the results from an investigation undertaken to compare the relative effectiveness of four Chemical Rinse Agents (CRAs) used for rinsing aircraft. The products were applied on a weekly basis to a series of flat alloy panels exposed to an oceanfront, marine atmospheric environment for two years. The results are presented and compared to those obtained from exposures of the same alloys that were not washed, were washed with ocean water, or washed with demineralized water. This report is a part of an ongoing study. Only the results of the exposures of aluminum alloys are presented in this report.

**Keywords:** Corrosion, rinsing aircraft, washing aircraft, aircraft birdbath, aluminum, titanium, steel, magnesium, aerospace, atmospheric corrosion, pitting corrosion, marine atmosphere, rinse agent.

## INTRODUCTION

### Aircraft Corrosion

Corrosion is a very difficult problem that costs commercial air fleet operators millions of dollars annually. The costs of corrosion in terms of military readiness cannot be measured, but they are believed to be even higher than for commercial operators.

Military hardware must often be shipped in haste to remote locations where it is operated in harsh environments with less time for maintenance and with limited maintenance facilities.

Figure 1 shows a typical Army refueling station during the deployment to the Persian Gulf in 1991.[1] The facilities at forward installations like this are very limited, and maintenance of equipment takes a back seat to operational demands. As a result of this combination of limited facilities and high operational demands, military aircraft often experience substantial corrosion damage during field deployment. Fortunately, much of the equipment spends a fair amount of its time in rear locations where facilities are not this limited and attempts at corrosion control and remediation are possible.

**FIGURE 1.** Helicopter refueling operation during Operation Desert Storm[1]

A number of proprietary products are marketed for rinsing aircraft for both the civilian and military markets. Unfortunately, these products have not been impartially evaluated, and government decision-makers do not have reliable data for making decisions on whether or not these products work and are worth their expense.

The purpose of this investigation was to determine if a number of proprietary CRAs could be used to prolong the life of Army aircraft deployed under circumstances such as those shown in Figure 1. The project was undertaken to compare the efficiencies of a number of commercial rinsing products and to determine if they offered measurable advantages over rinsing with water having no detergents or other chemical additives. A secondary purpose was to determine if these same products would reduce corrosion during training and other operations at rear areas where maintenance facilities are less limited.

## Atmospheric Corrosion Test Site

As shown in Table 1, the NASA Kennedy Space Center Beach Corrosion Test Site has been documented as having the highest corrosivity of any long-term exposure site in North America.[2] For this reason, the Army initiated a program to test alloys and corrosion control methods at this site. Figure 2 shows the rapid decrease in corrosion rates as distances from the beach increase.[3]

**TABLE 1:** Comparison of Corrosion Rates of Carbon Steel at Various Test Locations[2]

| Corrosion rates of carbon steel calibrating specimens at various locations | | | |
|---|---|---|---|
| **Location** | **Type Of Environment** | **µm/yr** | **Corrosion rate* (mils/yr)** |
| Esquimalt, Vancouver Island, BC, Canada | Rural marine | 13 | 0.5 |
| Pittsburgh, PA | Industrial | 30 | 1.2 |
| Cleveland, OH | Industrial | 38 | 1.5 |
| Limon Bay, Panama, CZ | Tropical marine | 61 | 2.4 |
| East Chicago, IL | Industrial | 84 | 3.3 |
| Brazos River, TX | Industrial marine | 94 | 3.7 |
| Daytona Beach, FL | Marine | 295 | 11.6 |
| Pont Reyes, CA | Marine | 500 | 19.7 |
| Kure Beach, NC (80 ft. from ocean) | Marine | 533 | 21.0 |
| Galeta Point Beach, Panama CZ | Marine | 686 | 27.0 |
| ***Kennedy Space Center, FL (beach)*** | ***Marine*** | ***1070*** | ***42.0*** |
| *Two-year average | | | |

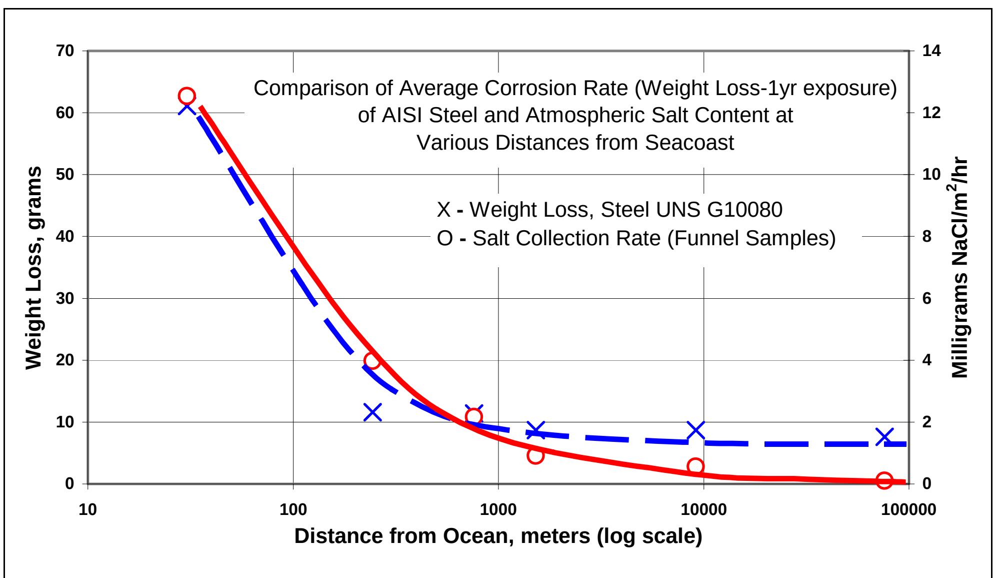


**FIGURE 2.** Changes of corrosion rate with distance from the ocean[3]

## EXPERIMENTAL PROCEDURES

### Alloys Tested

The alloys shown in Table 2 were chosen by the Army as being representative of the kinds of alloys most commonly used on military aircraft. The relative corrosion resistance of these alloys was evaluated in comparison tests where the alloys were exposed to the marine atmosphere with no rinsing, rinsing with ocean water, and rinsing with demineralized water as a control. This report presents the results of the two-year exposures of the aluminum alloys. The other alloys were still being evaluated at the time of this report.

**TABLE 2:** Alloys Tested in this Investigation

| UNS Alloy Designation | Composition | Designation This Study |
|---|---|---|
| G43400 | Fe, 0.4 C, 1.8 Ni, 0.8 Cr, 0.25 Mo | 4340 |
| S45850 | Fe, 18 Ni, 7.5 Co, 5 Mo, Ti, Al | C-250 |
| S35500 | Fe, 15.5 Cr, 4.5 Ni, 3 Mo | AM-355 |
| S13800 | Fe, 13 Cr, 8 Ni, 2 Mo | PH 13-8 Mo |
| A92024 | Al, 4.5 Cu, 1.5 Mg, 0.6 Mn | 2024-T3/8625 |
| J9100 | Al, 4.5 Cu, 1.5 Mg, 0.6 Mn | 2024-T3/5541 |
| A97075 | Al, Zn 5.6, 2.5 Mg, 1.6 Cu, 0.3 Cr | 7075-T6 |
| M11311 | Mg, 3 Al, 1 Zn | 4377/3171 or AZ31B-H24 |
| R65400 | Ti, 6 Al, 4 V | Ti-6Al-4V or Ti |

### Chemical Rinse Agents (CRAs) Tested

Table 3 shows the chemical analyses of the proprietary CRAs tested. The analyses were done using ion chromatography. Several of them are marketed with trade names implying that they will eliminate salt or chlorides.

**TABLE 3:** Chemical Analysis of Chloride Rinse Agents

| | Sample ID: | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Anions* | Fluoride | nd | 3477 | nd | nd |
| | Chloride | 60 | Nd | 110 | 232 |
| | Nitrite | 131 | Nd | 91 | 314 |
| | Nitrate | nd | 166 | 94 | 9511 |
| | Phosphate | 65 | 80 | 25191 | nd |
| | Sulfate | 92 | 227 | 1152 | 529 |
| Cations* | Sodium | 2367 | 1453 | 7930 | nd |
| | Ammonium | 1919 | 134 | nd | 36053 |
| | Potassium | 116 | 280 | 5537 | 1023 |
| | Magnesium | nd | Nd | nd | nd |
| | Calcium | 56 | 60 | 48 | nd |

*Concentration (ppm)  nd- not detected, below lower detection limits

### Exposure Testing

Flat specimen panels, 4 by 6 inches (10 by 15 cm) by 1/16 to 3/16 inches (0.16 to 0.48 cm) thick, weighing 40 to 1200 grams, were exposed for two years to the marine atmosphere environment in racks manufactured in accordance with standard industrial procedures.[4] Figure 3 shows the close proximity of the specimen panels to the Atlantic Ocean at Kennedy Space Center.

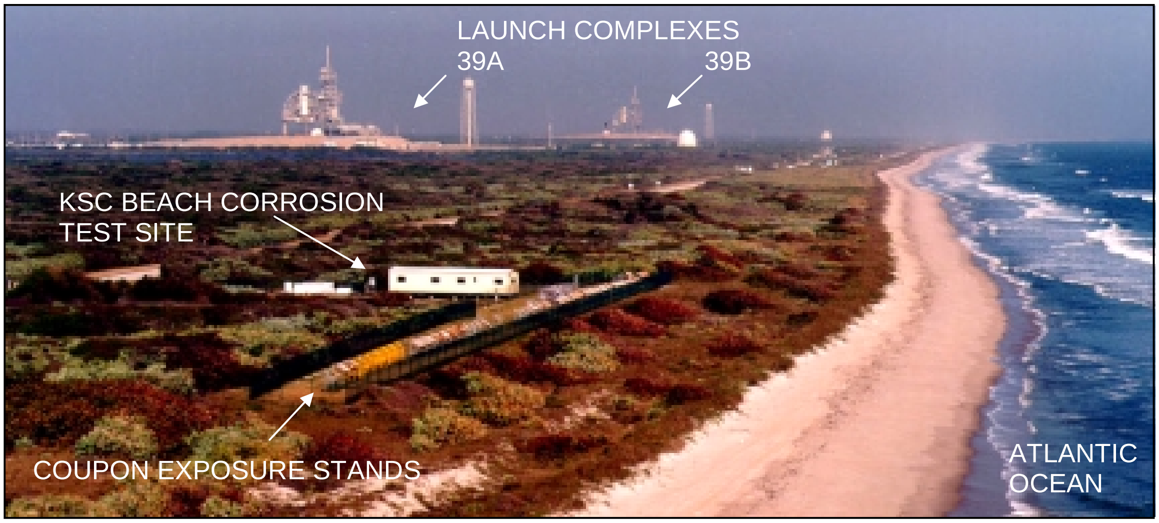


**FIGURE 3:** View of Beach Corrosion Site and Coupon Stands

### Rinsing Procedures

The specimen panels were rinsed once each week with a commercial pressure sprayer and the proprietary chemicals listed in Table 3 diluted according to the manufacturer's instructions.

### Ultrasonic tests

Some of the alloys tested experienced the delamination and exfoliation corrosion characteristic of aluminum alloys. Figure 4 shows one example of this delamination.

**FIGURE 4:** Exfoliation of corroded aluminum

Most of this delamination was observed on the 7075-T6 alloy specimens, although limited delamination was observed on some samples of other alloys. Ultrasonic tests were conducted to determine the extent of delamination on the 7075-T6 aluminum alloys. These tests were conducted in the field after approximately 23 months of atmospheric exposure.

### Corrosion Removal After Exposure

All coupons were first cleaned by using a pressure washer to remove the gross corrosion products, followed by a five-minute ultrasonic demineralized water bath, dried, and weighed. After the pressure water and ultrasonic wash process, the coupons were chemically cleaned in a specific solution according to metal type. The cleaning process for each alloy was determined using ASTM G1-90 (1999), Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens,[5] as a guideline. Solutions were chosen to remove the corrosion products with minimal dissolution of the base metal. The chemical cleaning process was repeated on each specimen several times, and the mass loss determined after each cleaning until a constant weight was reached. The removal of the corrosion products was confirmed by examination with a low power microscope. After the coupons were cleaned, they were retagged, photographed, and bagged for storage and further analysis.

## RESULTS AND DISCUSSION

### Weight Loss

None of the aluminum alloys showed significant weight loss, and weight loss of aluminum alloys cannot be used for rating the efficiencies of the CRA's under test.

### Pitting

Both the 2024/8625 and the 2024/5541 aluminum showed minor surface pitting while the 7075-T6 aluminum showed moderate to high pit densities. Table 4 shows the rating of the coupons using the ASTM G46-94 (1999), Standard Guide for Examination and Evaluation of Pitting Corrosion,[6] standard chart as a guideline. The pitting density (pits/$m^2$) ratings of <2500 (A-0), 2500 (A-1), 10,000 (A-2), 50,000 (A-3), 100,000 (A-4), and 500,000 (A-5), per ASTM G-46 are included. Pit area ratings B and pit depth ratings C are shown, each with six levels, 0 through 5, each increase in level indicates an amount of more corrosion.

- <u>Pit area</u>: 0.0 (0), 0.0 - 0.5 (B-1), 0.5 - 2.0 (B-2), 2.0 - 8.0 (B-3), 8.0 - 12.5 (B-4), and 12.5 $mm^2$ and greater (B-5)

- <u>Pit depth</u>: 0.0 (0), 0.0 - 0.4 (C-1), 0.4 - 0.8 (C-2), 0.8 - 1.6 (C-3), 1.6 - 3.2 (C-4), and 3.2 mm and greater (C-5).

**TABLE 4.** Analysis of Aluminum Coupons with Significant Pitting

| **2024/8625** Rinse | ASTM rating | Area $mm^2$ | ASTM rating | Depth mm | ASTM rating |
|---|---|---|---|---|---|
| CRA #1 | A-2 | 0.017 | B-1 | 0.034 | C-1 |
| CRA #2 | A-3 | 0.025 | B-1 | 0.066 | C-1 |
| CRA #3 | A-2 | 0.013 | B-1 | 0.030 | C-1 |
| CRA #4 | A-2 | 0.017 | B-1 | 0.038 | C-1 |
| DM $H_2O$ | A-2 | 0.008 | B-1 | 0.046 | C-1 |
| Exposure | A-3 | 0.031 | B-1 | 0.044 | C-1 |
| Seawater | A-3 | 0.018 | B-1 | 0.054 | C-1 |

| **2024/5541** Rinse | ASTM rating | Area $mm^2$ | ASTM rating | Depth Mm | ASTM rating |
|---|---|---|---|---|---|
| CRA #1 | A-3 | 0.049 | B-1 | 0.078 | C-1 |
| CRA #2 | A-4 | 0.385 | B-1 | 0.126 | C-1 |
| CRA #3 | A-2 | 0.031 | B-1 | 0.044 | C-1 |
| CRA #4 | A-4 | 0.126 | B-1 | 0.096 | C-1 |
| DM $H_2O$ | A-2 | 0.018 | B-1 | 0.050 | C-1 |
| Exposure | A-2 | 0.025 | B-1 | 0.078 | C-1 |
| Seawater | A-3 | 0.049 | B-1 | 0.078 | C-1 |

| **7075-T6** Rinse | ASTM rating | Area $mm^2$ | ASTM rating | Depth mm | ASTM Rating |
|---|---|---|---|---|---|
| CRA #1 | A-3 | 0.018 | B-1 | 0.046 | C-1 |
| CRA #2 | A-4 | 0.385 | B-1 | 0.104 | C-1 |
| CRA #3 | A-2 | 0.085 | B-1 | 0.064 | C-1 |
| CRA #4 | A-5 | 0.785 | B-2 | 0.096 | C-1 |
| DM $H_2O$ | A-2 | 0.159 | B-1 | 0.064 | C-1 |
| Exposure | A-3 | 0.071 | B-1 | 0.046 | C-1 |
| Seawater | A-3 | 0.132 | B-1 | 0.058 | C-1 |

Table 4 presents the actual data collected and incorporates ASTM G-46 for rating of the coupons. It can be seen that just using the ASTM rating without looking at the data is not sufficient. For the 7075-T6 alloy, the CRA #1, CRA #2, and CRA #3 have the same B and C ratings giving the indication that the pitting is equal, but the data is quite different. CRA #1 worst-case pit area is 20 times smaller than CRA #2 worst pit area. CRA #2 has a pit depth two times greater than CRA #1.

Figure 5 below shows the comparative amounts of pitting experienced on 7075-T6 aluminum with four different chemical rinse agents. The region shown for each sample is the center 1 $cm^2$ of the sample. It is obvious that the two rinse agents shown on the right (CRA-2 and CRA-4) produced more corrosion pitting than the weekly washing with demineralized water shown in the center of Figure 5. In a similar manner, the relatively smaller pits (Table 4) associated with the two left rinse agents (CRA-1 and CRA-3), in Figure 5, indicate that washing with these rinse agents is less corrosive than washing with demineralized water. The true comparisons for all the rinse agents was the weekly washing with demineralized water, ocean water, and the samples which were exposed to the natural marine atmosphere that received no rinsing.

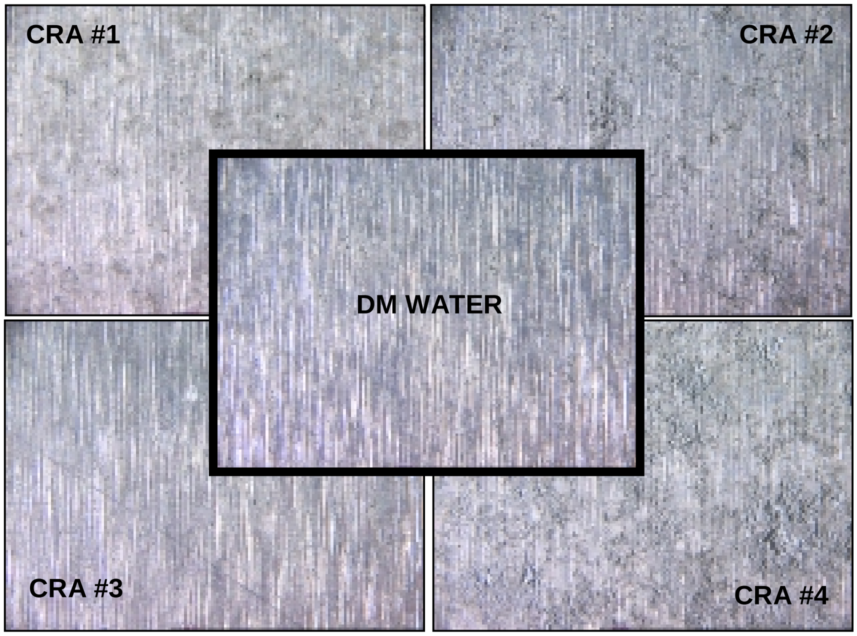


**FIGURE 5:** Comparison of the pitting occurring on 7075-T6 aluminum panels washed with demineralized water and four different chemical rinse agents.

### Ultrasonic tests

The 7075-T6 aluminum showed exfoliation indicative of intergranular corrosion along the edges of the panels with some of the rinse agents. Ultrasonic tests were conducted to determine the extent of delamination on the 7075-T6 aluminum alloys. Figure 6 shows the regions of delamination determined by ultrasonic inspection on the replicate samples exposed to one of the CRA's.

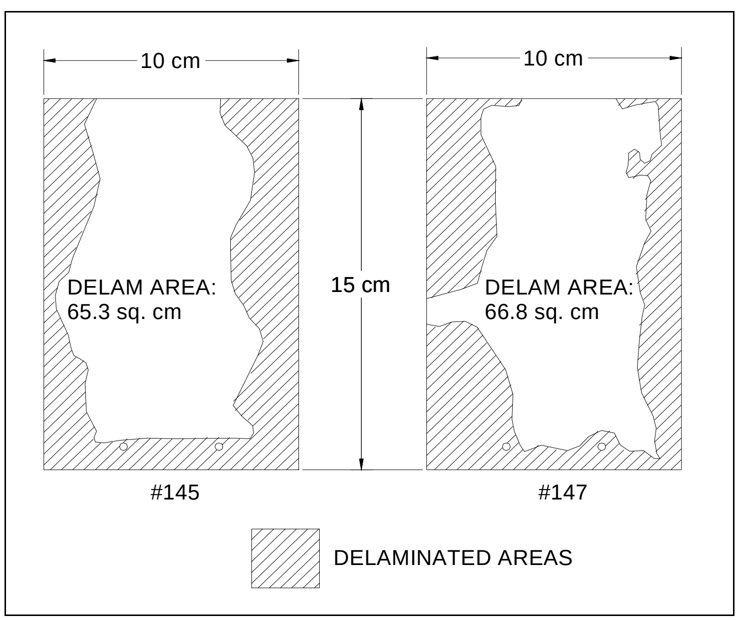


**FIGURE 6.** Typical Test Coupons Showing Graphical Delaminated Areas

In agreement with table 4 and Figure 5, CRA-2 and CRA-4 were more corrosive than demineralized water, ocean water, or exposure only. The total amount of delamination on the samples rinsed with CRA 3 was approximately the same as on the samples rinsed with ocean water and rank with DM Water and Exposure Only.

The data in Table 5 shows that, while the general trends are as discussed in the above paragraphs, there were significant variations in the amount of delamination detected on replicate samples. While general trends can be identified with this data, precision is not to be expected.

**TABLE 5:** Summary of Delaminated Areas (7075-T6)

| Rinse | Coupon # | Delaminated Area ($cm^2$) | % Area Damaged | Average for CRA |
|---|---|---|---|---|
| #1 | 139 | 0.8 | 0.6 | 0.3 |
| | 141 | 0.0 | 0.0 | |
| #2 | 145 | 65.3 | 43.5 | 44.0 |
| | 147 | 66.8 | 44.5 | |
| #3 | 151 | 9.2 | 6.1 | 3.1 |
| | 153 | 0.0 | 0.0 | |
| #4 | 157 | 126.6 | 84.4 | 46.3 |
| | 159 | 12.2 | 8.1 | |
| Ocean Water | 163 | 0.0 | 0.0 | 3.3 |
| | 165 | 10.0 | 6.7 | |
| DM Water | 169 | 1.7 | 1.1 | 1.1 |
| | 171 | 1.6 | 1.0 | |
| Exposure Only | 175 | 0.0 | 0.0 | 2.0 |
| | 177 | 6.1 | 4.1 | |

## CONCLUSIONS

1. Rinsing the alloys tested with demineralized water on a weekly basis reduced the corrosion of the coated 2024 aluminum alloys tested.
2. One of the chemical rinse agents tested (CRA-1) reduced the exfoliation corrosion of aluminum alloys more than rinsing with demineralized water.
3. Two of the chemical rinse agents tested (CRA-1 and CRA-3) reduced the pitting corrosion of the 7075-T6 aluminum alloy more than rinsing with demineralized water. These CRA's produced similar results for all alloys tested.
4. Two of the chemical rinse agents tested (CRA-2 and CRA-4) resulted in more corrosion on the aluminum alloys tested than rinsing with demineralized water. Also these two rinse agents produced more corrosion on aluminum than weekly rinsing with ocean water and exposure only.

In conclusion, it is better to rinse the aluminum alloys with demineralized water over rinsing with ocean water or not rinsing at all. CRA-1 could be considered for rinsing 7075-T6 aluminum alloys if economically warranted.

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